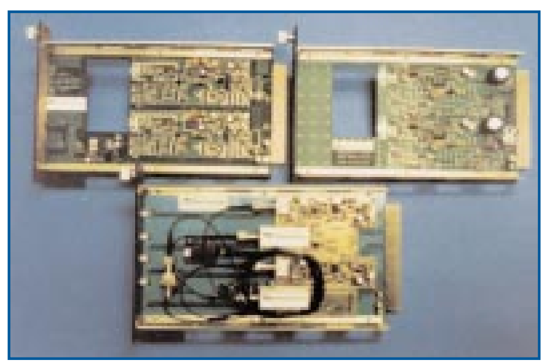
SPECIAL REPORT

June 2001

Ballistic Missile Defense Organization

BMDO Fiber-Optic Technologies for Telecommunications

Part II: Optical Switches and Circuitry



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IN COOPERATION WITH THE BALLISTIC MISSILE DEFENSE ORGANIZATION OFFICE OF TECHNOLOGY APPLICATIONS

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BMDO FIBER-OPTIC TECHNOLOGIES FOR TELECOMMUNICATIONS

Part II

OPTICAL SWITCHES & CIRCUITRY

BALLISTIC MISSILE DEFENSE
DEPARTMENT OF DEFENSE

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TECHNOLOGY APPLICATIONS PROGRAM

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Cover photographs:
Top: Corning Applied Technologies' polarization controller.
Center: Radiant Research's optic lab.
Bottom right: BroaData's multimedia extenders.

TABLE OF CONTENTS

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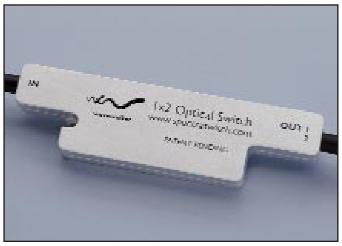
INTRODUCTION



An optical switch from SpectraSwitch, Inc.

Fiber-Optic Technologies for National Defense and Commercial Use

The dot.com rush may be over, but make no mistake, telecommunications carriers will still face a booming market in the coming years. As customers start to fully utilize newly installed metro- and local-access fiber loops and broadband-to-the-home connections, more demand will be put on the long-haul fiber routes. The glut of bandwidth now enjoyed by telecommunications carriers will soon be soaked up by Internet Web agents, computer-to-computer communications, Internet telephony, streaming digital video and audio, and countless other services. In short, demand for bandwidth will grow at an average rate of more than a 100 percent per year for the next 10 to 15 years, as estimated by Corning, Inc.

To meet this demand and to stay competitive, telecom carriers want to squeeze as much performance as they can out of the fiber-optic lines already installed. Telecommunications networks are currently hybrid in nature, using both optics and legacy electronics for signal transmission and processing. In response to this unprecedented consumer demand for bandwidth, carriers are converting their networks into ultrahigh-bit-rate all-optical systems. These advanced networks require next-generation all-optical components that are reliable, are capable of meeting stringent performance requirements, and can provide increased processing functionality.

One successful approach already applied has been wavelength division multiplexing (WDM), which allows transmission of multiple signals through one single strand of fiber. Recently developed multiplexing technology upped the amount of traffic that can be carried on a single link from 1 and 2.5 Gbits/sec to between 10 and 40 Gbits/sec. This means carriers can get over a ten-fold increase in efficiency per line. And 400 Gbits/sec and even 1000 Gbits/sec—terabit-level capacity—may await in the near future.

However, what holds carriers back from enjoying these greater gains of optical networking is the electrical equipment in place to route signals. Present-day electrical switches only work in the 2.5 Gbits/sec range. The answer to this problem may come in the form of optical-core photonic switches. Unlike electrical-core switches, these devices don't convert signals between photonic and electric formats for routing and hence can keep pace with these new throughputs. So the telecom industry is eager for an optical-core switch that is robust enough to use at commercial levels. Thus far, no optical-core photonic switch has been sufficiently developed to capture this potentially lucrative market, though scores of companies are on the verge of offering possible solutions, including some strong contenders originating from an unlikely source—The Ballistic Missile Defense Organization (BMDO).

Development Now for the Future

If you think telecommunications carriers need fast communications and processing equipment, then imagine what BMDO must require. BMDO is chartered within the Department of Defense to manage, direct, and execute a Ballistic Missile Defense (BMD) program. Given the proliferation of ballistic missile systems and weapons of mass destruction, the country must deploy a family of missile defense systems to protect the U.S. homeland, forward-deployed and expeditionary armed forces, as well as our friends and allies from the threat of long- and short-range ballistic missile attack.

BMDO's high-risk approach to technology involves taking chances on ideas that even corporate R&D labs may not risk. And it is paying off with technologies that will be the basis of tomorrow's information highway.

The network infrastructure for these operations, called the Battle Management Command, Control, Communications, Computers, and Intelligence (BM/C^4I) operations, will play a crucial role in defense. BM/C^4I collects data from the surveillance systems, interprets the data, communicates the information between the various military systems and, using this information, enables complex battle management decision making. A tremendous amount of synchronization between multiple and sometimes distant ground and air subsystems is required, and response times must be the fastest possible.

So naturally, when mounting a defense against a threat, a BMDO system can't afford a bottleneck anywhere in its network. Throughput is a life-or-death matter in missile defense.

Fortunately, the technologies that BMDO develops play a role in relieving the communications bottlenecks in the civilian world as well. To ensure that BMDO systems continue to operate with the most advanced technology possible, it invests about 10 percent of its research and development (R&D) budget in innovative technologies and concepts that hold the promise of great leaps forward in performance and cost reduction. From waveguides with high gain to optical circuits, these technologies could be the innovative new system elements that help enable the next generation of ballistic missile defense weapons systems. In addition many of the technologies developed for other BMDO needs, such as piezoelectric thin films for sensors, can serve the telecommunications industry as well.

Many of these new ideas come from small companies and academia. BMDO's Small Business Innovation Research (SBIR) program provides a single point of contact for small companies with big technology ideas. The SBIR program was established by Congress in 1982 to expedite the conversion of small business research findings into commercial products. SBIR gives companies the opportunity to test high-risk theories and develop innovative technologies. Many of the technologies featured in this report are SBIR-based. BMDO has also invested in university research as a source for new ideas through the Innovative Science and Technology (IS&T) program, which was first formed by the Strategic Defense Initiative Organization (SDIO), BMDO's predecessor, to explore advanced technologies that were beyond the realm of Federal or corporate research and development labs.

The goal of such programs is to develop advanced technology and get it out into the marketplace, where it can mature and hopefully be spun back into a BMDO system. Making a successful commercial product out of a technology ensures the viability of that product in the long run, reduces its cost through mass production, and provides performance and reliability data at no charge to the government. By understanding opportunities in the commercial market, BMDO has repeatedly leveraged R&D funding from private industry to co-develop a technology. In addition, many of the technologies that U.S. missile defense systems use today are available as inexpensive commercial-off-the-shelf components, thanks to the commercialization of a BMDO technology years ago.

This high-risk approach to technology investment involves taking chances on ideas that even the corporate R&D labs may not risk. And it is paying off with technologies that will be the basis of tomorrow's high-speed information highway.

How BMDO Technologies Address Commercial Needs

This report, the second installment of *BMDO Fiber-Optic Technologies for Telecommunications*, features fiber-optic telecommunications technologies that have been developed with the help of BMDO research funds. The first section covers the different approaches BMDO companies are taking to solve the electrical switch bottleneck. A few companies, such as SpectraSwitch, Chorum, and Radiant Research, are pursuing designs that utilize advanced materials capable of switching the direction of a signal with an application of voltage or other input.

The second section highlights technologies that address problems inherent in higher capacity systems, for instance polarization mode dispersion (PMD). To achieve the higher bandwidth-per-link that advanced wavelength division multiplexing promises, the spacing between channels must shrink from 100 to around 25 GHz. When left uncorrected, signals this tightly packed can blur together. Corning Applied Technologies can answer the dispersion problem with a polarization controller based on a class of materials developed, in part, with BMDO SBIR funding. Other technologies address future needs in component manufacturability, signal amplification, and high-speed processing.

Doubtless, many of these BMDO technologies will find widespread acceptance in the marketplace.

Doubtless, many of these solutions will find widespread acceptance in the marketplace. After all, many of the technologies and their attendant companies featured in the first installment of the *BMDO Fiber-Optic Technologies for Telecommunications*, published in 1998, achieved considerable success. Coherent's highly efficient optically pumped semiconductor laser is being looked at by manufacturers for a number of different telecommunications products and has achieved considerable commercial success in the telecom component testing market. Radiant Research, now Radiant Photonics, has also enjoyed strong sales with the tunable wavelength division multiplexer (WDM) featured in that report as well. In 1999, photonic equipment giant Nortel Networks purchased CoreTek, featured in the first edition, largely on the strength of CoreTek's tunable laser. Similarly, E-TEK Dynamics, with a wideband isolator that was featured in the previous edition, was acquired by JDS Uniphase, one of the world's leading supplier of parts for fiber-optic equipment. Not to be outdone, Ortel, with its laser array transmitter, was purchased by Lucent Technologies in April 2000. And finally, C- and L-band optical amplifier provider Optigain was courted by fiber-optic cable manufacturer Fitel Technologies, which acquired a majority equity position in the company. Investment from larger companies isn't the sole measure of success, of course, but when smaller firms such as these are invested in by industry giants, they are provided with the necessary funds to ramp up production of their BMDO technologies, giving such products greater market penetration.

The next few years will be turbulent ones for optical component vendors. But one thing is for certain: the technologies in this report, like those in the previous edition, will play a part in building this country's information superhighway.

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PHOTONIC SWITCHES

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THE HOT MARKET OF OPTICAL-CORE PHOTONIC SWITCHES

Introduction

In telecommunications networks, switches redirect signals. A telephone call made in New York, for instance, must pass through a number of different lines to get to its proper destination in, say, Chicago. And while most of the journey is undertaken as a stream of light zipping through long-haul fiber-optic lines, the "switching" needed to direct the call-turned-signal between pathways must be done electrically, on technology leftover from when trunk lines were electrically based cable. This is a time-consuming, inefficient process, since each signal must be converted multiple times.

As a result, telecommunication giants like AT&T and Sprint are eager for devices that can switch signals while leaving them in their photonic states. Such "optical switches" can cut the response time, thereby allowing for more signals to be sent through already-installed fiber-optic cables. Optical switches would also improve reliability, enabling calls to be instantaneously rerouted should system trouble occur.

Employing an all-optical network may cut costs as much as 80 to 90 percent.

All told, deploying an all-optical network can cut operation costs by as much as 80 to 90 percent, according to many industry analysts. So it comes as no surprise that the market for optical switches, according to investment research firm Gruntal & Company, might be $900 million in 2002, and easily reach the multi-billion dollar range shortly thereafter.

BMDO is no stranger to the need for faster communications. The organization has invested in developing new switching technologies to better meet the requirements of future data communications systems. In this section, we present six companies redeploying BMDO-funded technology into the telecommunications market. Three are building solid-state optical-core photonic switches. All three technologies are based on advanced materials that can shift a signal's direction based on its wavelength or polarization state. Austin, Texas-based Radiant Photonics has developed a model, available summer 2001, is insensitive to the polarization differences or slight wavelength variations of incoming signals, eliminating the need for expensive correcting equipment. Richardson, Texas-based Chorum Technologies developed a switch—part of its PolarShift™ line of optical components—that features crosstalk of less than -60 decibel (dB) and an insertion loss of less than -1.5 dB. And Santa Rosa, California's SpectraSwitch has introduced the WaveWalker™ line of low-port count switches that features non-stick reliability, bi-directional signal paths, and billion-cycle durability.

While these companies are poised to meet the immediate market demand for photonic switches, Templex Technology Corporation, in San Jose, California, is looking towards the next generation of fiber-optic networks. This company has developed a passive optical grating, called SmartOptical™, that would minimize the need for switching equipment altogether and increase today's data rate of metro networks by a factor of 100. Zephyr Cove, Nevada's OptiComp has developed another approach, called a distributed opto-electronic crossbar system, that would facilitate terabit-level throughput as well. And Torrance, California's BroaData Communications is addressing the rapidly growing market for fiber-optics in local intra-office and metro-area networks. Using BMDO opto-electronic crossbar array research from its parent company Physical Optics Corporation, BroaData has created a line of full-duplex multimedia extenders that enable the simultaneous transmission of audio, video, and data content along one strand of fiber.

RADIANT PHOTONICS' ROBUST PHOTONIC SWITCH

Radiant's research into polymers has produced a cutting-edge photonic switch.

Radiant Photonics, Inc. (Austin, TX), is developing an optical-core switch that promises to be more versatile and robust than competing technologies, thanks to the use of electro-optic polymers. Radiant's Thermo Optical Integrated Circuit (TOIC™) technology allows for the design, manufacture, and delivery of cost-effective, high-performance transport and switching components. Radiant's TOIC technology provides functional integration at the chip level for the delivery of high-value optical modules and subsystems, as well as offering unprecedented integration opportunities to optical system-manufacturers.

Technology Description

Radiant's switching technology relies on polymers used to make thermo- or electro-optic prisms. Such prisms can vary their index of refraction in response to a change in temperature (thermo-optic) or an input voltage (electro-optic). By directing where the input signal hits a diffraction grating, the prism can control which output fibers the signal will enter. The multifunctional gel polymers are made by doping the gelatin to obtain the desired refractive characteristics. The polymers are also used in the switch's beam deflector.

There are several other polymer-based switching technologies in development by competing companies; however these approaches involve complicated phase delays, which can be sensitive to polarization differences or slight wavelength variations that are inherent in less-than-perfectly-transmitted signals. Thus Radiant's switch would reduce the need for more expensive lasers and related correcting equipment. It would also have faster response times than the micro-mechanical switches, which, because of their mechanical nature, are not as fast acting nor as reliable.

Radiant's switch performs equally well over all currently used communications bands (C, L, and S bands), provides faster switching speeds (down to 1 nanosecond vs. 10-15 milliseconds [ms] for electric-core switches and 4 ms for other proposed optical-core switches), and features low insertion losses (less than 1 decibel). The interconnect may be designed to accommodate up to 50 output channels. Radiant plans to begin commercial production of its photonic switches by summer 2001.

Technology Development and Transfer

BMDO funded work to develop multifunctional polymeric materials to facilitate signal amplification, electro-optic switching, and waveguide hologram formation. BMDO needed a polymer for high-speed fiber-optic components that would be stable at temperatures from -170 degrees C to +180 degrees C, which would cover most of the requirements of airborne and spaceborne optical interconnect applications.

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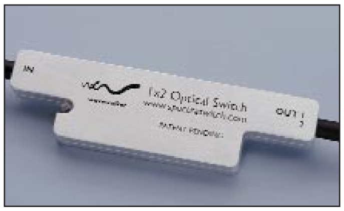

SpectraSwitch's WaveWalker line of optical switches is based on liquid crystal technology.

SPECTRASWITCH GOES THE CRYSTAL ROUTE

SpectraSwitch, Inc. (Santa Rosa, CA), is developing the WaveWalker™ portfolio of optical components for telecom switching and signal conditioning applications. The first product SpectraSwitch has introduced is a low-port-count ("low-port-count" means that there are a limited number of output lines per switch) photonic switch used in single mode transport fiber, the WaveWalker 1 × 2 Optical Switch. Designed to meet the performance requirements of the all-optical network, this switch offers a smart alternative for low-port-count switching and signal conditioning applications.

Technology Description

SpectraSwitch's patent-pending technology is based on liquid crystal, coupling the phenomenon of birefringence (the ability to refract an unpolarized light into two separate, orthogonally polarized rays) with liquid crystal's response to an induced electric field. An liquid crystal cell rotates the polarization of incoming light when a voltage is applied. SpectraSwitch's liquid crystal-based components provide greater reliability, faster switching speeds, and lower power consumption than other devices in production or currently being developed, and are particularly well suited for protection, reconfiguration, and test and measurement applications.

Technology Development and Transfer

SpectraSwitch's liquid crystal technology research was funded in part by a BMDO SBIR Phase II contract for use in optical components. SpectraSwitch has invested much research and development into enhancing the material properties of liquid crystal to bring it from the technology ubiquitous in flat-panel displays and handheld devices to achieve the increased contrast ratio necessary for its use in infrared telecom applications.

SpectraSwitch's optical components provide performance advantages over the switches currently in use and other all-optical models now in development. One benefit to this robust liquid crystal platform is that it enables the production of components with much reduced switching speeds—from the current industry standard for legacy optomechanical switches of 10 to 15 milliseconds (ms) to less than 4 ms. Since the materials can withstand rugged environments and are immune to vibration-induced performance degradation, they are expected to have billion-cycle durability, a vast improvement over the incumbent's 10-million cycle lifetime specification.

SpectraSwitch plans to further develop its WaveWalker line of components to include variable optical attenuators, optical add/drop multiplexers, polarization mode dispersion compensators, and multifunctional modules.

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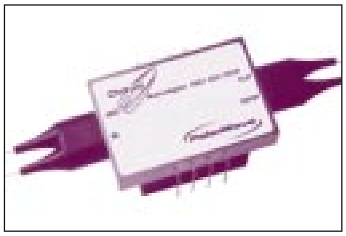

The solid-state optical switch offered by Chorum employs a patented fault-tolerant architecture.

CHORUM'S SWITCH GOES LOW ON CROSSTALK AND INSERTION LOSS

Chorum Technologies, Inc. (Richardson, TX), has developed a solid-state optical switch with crosstalk and insertion loss specifications comparable to standard opto-mechanical switches now in use. The company is using a patented fault-tolerant architecture to build this switch, which makes it ideal for network protection and restoration applications that require highly reliable switching with response times under milliseconds. A commercial version of this optical switch is sold under Chorum's PolarWave™ optical product line, and is suited for the metro and local access markets.

Technology Description

Chorum's fault-tolerant architecture has three key features: 1) polarization manipulation; 2) complimentary polarization design; and 3) a method for eliminating undesired optical energies. The polarization manipulation provides the basis for optical switching with no moving parts. The complimentary polarization design provides a high-polarization extinction-ratio conversion using liquid crystal switching elements. Finally, the energy elimination method enables high-performance (submillisecond performance) and a crosstalk of less than -45 decibel (dB), independent of the operating environments and conditions. The switch offers an insertion loss of less than -1.3 dB.

Other key advantages of this switch include low power consumption, a wide operating spectrum, polarization insensitivity, millisecond to submillisecond response times, and temperature insensitivity. With the use of liquid crystal technology for the switching operation, no moving parts are involved in the process, resulting in an extremely reliable device.

Technology Development and Transfer

In 1997, BMDO awarded a SBIR Phase II contract to Chorum Technologies, then known as Macro-Vision Communications, LLC, to develop a state-of-the-art optical switch for BMDO optical signal processing applications.

From this research, Chorum now offers its PolarWave line, which consists of a fast add/drop switch and a 1 × 2 switch. Chorum Technologies is now developing customized optical modules for optical networking system vendors. In addition to the optical-core switch, the PolarWave line also includes optical filters, optical processors, and integrated optical subsystems.

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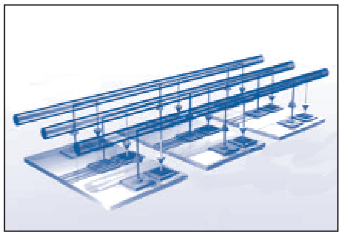

The opto-electronic logic array developed by OptiComp may reduce switching requirements.

OPTICOMP'S DISTRIBUTED OPTICAL LOGIC ARRAYS

OptiComp Corporation (OCC; Zephyr Cove, NV) has developed an opto-electronic logic array (OLA)-based distributed crossbar switch that can provide terabit-level end-to-end throughput. Called SmartCross™, this crossbar switch can be integrated into 1.3 µm-based storage-area networks (SANs), local-area networks (LANs), metropolitan-area networks (MANs), and wide-area networks (WANs). The technology can reduce key central switching requirements within datacom and telecom networks.

Technology Description

OCC's optical-core switching components are based on Vertical Cavity Surface Emitting Laser (VCSEL) technology operating in the 1.3 µm wavelength band. The distributed crossbar switch introduces a robust system that will significantly enhance end-to-end performance so that bandwidth-intensive applications can be realized with zero latency. Conventional opto-electronic crossbars require a central switching apparatus (switching box) to implement the address decoding, which lengthens routing times and necessitates additional hardware costs. With a distributed opto-electronic crossbar system, the address decode function is divided between processors, leaving only the true distance interconnect to be implemented by optical means. This enables the switching within a network to be performed more efficiently by the electronics while the optical elements perform the high data rate transfer function. For example, unlike most networks such as LANs, MANs, and SANs, which consist of a hierarchy of central switches and servers, the distributed crossbar supports high levels of fan-in and fan-out switching. As a result, users will be able to achieve terabit-per-second end-to-end delivery.

Technology Development and Transfer

Development of the SmartCross™ switch has been substantially accelerated by two development contracts awarded by BMDO and DARPA. The BMDO work concentrates on producing cost-effective 1.3µm VCSELs for massive parallel optical interconnects.

Utilizing the crossbar technology, OCC is planning a range of components and subsystems that will be targeted for integration into long- and short-distance networks. Specifications for beta-site testing are now being solicited from industrial partners. OCC's product line is expected to significantly improve cost/performance ratios of its target applications relative to current and forecasted competitive implementations. OCC facilities include engineering and light manufacturing Class 100/1000 cleanrooms with a test laboratory for device analysis and evaluation. The addition of epitaxial-growth capacity during the second quarter of 2001 gives OCC a vertically integrated manufacturing capability for its product suite.

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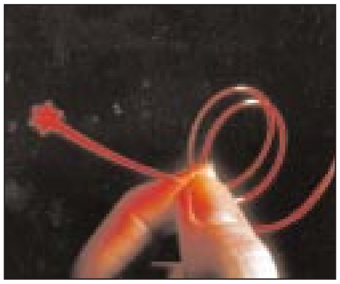

Today's metro fiber optic networks may enjoy increased capacity thanks to Templex's optical grating.

TEMPLEX GUNS FOR MULTI-GIGABIT CAPACITY METRO NETWORKS

Templex Technology, Inc., (San Jose, CA) has developed an optical coding and encoding technology based on fiber Bragg gratings that would increase the optical throughput in a metro/access environment while minimizing the need for costly routing equipment. The company plans to use this technology as a basis for optical subsystems that can increase the efficiency and capacity of today's networks 100-fold. Thus far, the company has released a commercial high performance fiber Bragg grating product line, called SmartFBG™, for ultra narrow channel spacing, dense wavelength division multiplexer (DWDM) market.

Technology Description

Templex's key to more capacity and efficient distribution of the increased capacity is a passive all-optical routing and switching protocol based on complex gratings about the size of a microscope slide. To form this grating, complex periodic variations in the index of refraction of the glass are produced lengthwise along a fiber. The Templex fabrication process controls all parameters that affect performance, allowing construction of optical filters that have unprecedented complexity and performance. Fiber Bragg gratings feature low insertion loss, small size, high tensile strength, and superior spectral characteristics.

The grating is designed so that the refractive index modulation causes light of a specific wavelength, making it useful for separating and switching signals. Typically, the grating is used as a filter to select (or separate) a given wavelength. However, the complex fiber Bragg grating can also be used as an encoder to put an optical code or a "stamp" on every pulse of light. When a light pulse of short duration is reflected by a carefully designed grating, the light is reshaped, delayed, and stretched into a uniquely coded light pulse. The temporal shape of this optical signal can then be used for multiplexing and demultiplexing information, thereby eliminating electronic conversion. Different codes can be imparted on pulses depending on the destination and/or quality of the service requirements.

Technology Development and Transfer

In August 1997, BMDO awarded Templex a $1 million 2-year FasTrack Phase II SBIR contract to pursue novel switching and control devices for all-optical networking. This work led to the development of encoders and decoders based on fiber Bragg gratings. The encoding and decoding based on codes is called Optical Code Division Multiplexing (OCDM). Templex Technology's OCDM is the only coding technology that is fully compatible with DWDM and is expected to enhance the metro/access network needs for higher capacity.

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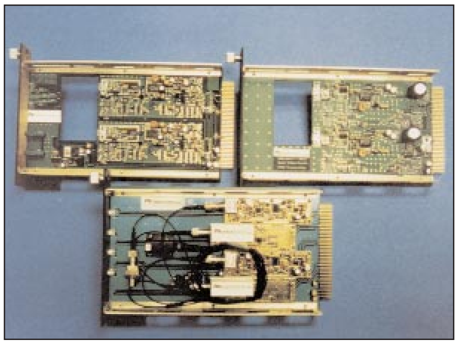
BROADATA'S LOCAL FIBER SOLUTIONS



BroaData's multimedia extender allows audio, video, and data to be transmitted over one fiber-optic cable.

BroaData Communications, Inc. (BCI; Torrance, CA) offers a series of duplex multimedia extenders that, utilizing a crossbar technology developed in part for BMDO, can be used for the simultaneous transmission of audio, video, and data content along one fiber. The opto-electronic crossbar array provides fast, reconfigurable switching of signals between multiple input and output channels.

Technology Description

The opto-electronic crossbar combines signal fan-out and fan-in operations with electronic modulation of laser sources. It is composed of three plane modules, which can be stacked on each other to produce a very compact device. The crossbars, with switching speeds range from 0.1 to 30 microseconds, are compatible with fiber-optic communications standards. The opto-electronic crossbar can provide fast signal switching in various fiber-optic-based multimedia networks. Other applications include high-speed signal switching, reconfigurable networks, and signal multiplexing.

Technology Development and Transfer

The BMDO SBIR program funded this technology to provide fast, reconfigurable networks and to improve computer communication systems. The research was undertaken by Physical Optics Corporation (POC; Torrance, CA), and was incorporated into a family of multimedia extenders by BroaData, now an independent company spun off from POC. The extenders allow audio, video, and data content to be transmitted simultaneously over a single-fiber cable, offering the customer savings on installation costs and reducing the number of installed repeaters. These products utilize a physical-layer-only technique to multiplex and demultiplex multiple independent multimedia data channels on a single-fiber pair, increasing network connectivity and reducing network wiring complexity. It can work with RS232/RS422, Ethernet/Fast Ethernet and T1/E1 protocols.

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WAVEGUIDES AND OPTO-ELECTRONIC CIRCUITRY

2

OPTICAL CIRCUITRY KEEPS THE PACE

Introduction

Although photonic switches are today's hot ticket for cutting-edge optical component builders, the improvements in capacity they bring will necessitate higher-performance supporting equipment as well. Advances in everything from the circuitry needed to process all these broadband signals to the basic glass fiber that carries these signals will be sought. BMDO has invested heavily in multiple research areas related to optical communications, hoping the advancements will lead to faster communications for its own systems.

A polarization controller offered by Corning Applied Technologies.

One recurring trend in the industry is the movement away from mechanically driven components to solid-state ones. Solid-state components offer more rugged design, faster response times, and better reliability than mechanically driven devices. In particular, materials that can change the direction, polarization, or other attributes of a light signal by mere application of a voltage are piquing the interest of the industry. These materials can easily be incorporated into a package that can perform the same functions as a mechanical attenuator or beamsplitter, but take up less room and offer better reliability.

For instance, with BMDO SBIR funding, one small company, Woburn, Massachusetts-based NZ Applied Technologies developed a class of opto-electronic materials that can do exactly this. Called OptoCeramics™, these materials led to an attenuator that is one-tenth the size of other compact attenuators on the market. The company has since been purchased by Corning Inc., and now goes under the name Corning Applied Technologies. Corning Applied Technologies recently released an OptoCeramic polarization controller that can be used to alleviate polarization-mode dispersion (PMD)—a growing problem for telecommunications companies upgrading to 10- and 40-gigabit fiber-optic equipment. Transmission rates per wavelength can be improved as well. In Essex Junction, Vermont, TeraComm Research is developing a fiber-optic transmitter that will offer terabit-level encoding speeds, far surpassing even the cutting edge 40 gigabit-per-second models now being developed.

Using the latest methods from nanoparticle research, another company, NanoSonic, located in Blacksburg, Virginia, is refining a molecular self-assembly process, called electrostatic self-assembly, that can produce nonlinear optical thin-film materials with nanoscale-level molecular uniformity. Component builders take note: when this process is developed (in the next two to five years), the resulting films could be incorporated into frequency converters, optical modulators, and beamsplitters, making such components lighter, faster, and more tunable. Enterprising manufacturers also would be well-advised to take a close look at an erbium-amplifier glass offered by Kigre of Hilton Head, South Carolina, which offers a higher gain than materials required by today's optical amplifiers. This high-performance phosphate glass is processed through a unique ion exchange in which the glass trades ions with a solution to alter its index of refraction. It could be used in lossless splitters, waveguides, fibers, amplifiers, and wavelength-division multiplexers (WDMs).

The optical component industry is moving away from mechanical devices and toward solid-state solutions.

As the demand for opto-electronic components increases, the industry will require more efficient manufacturing techniques. The Miami, Florida-based company New Span Opto-Technology is developing a method of dynamically coupling waveguides to optical components. Rather than coupling waveguides to devices and hoping the two are aligned, manufacturers can now laser-write the waveguide's index of refraction specifically to the component's output. This will eliminate many a headache for manufacturers of WDMs, transceivers, and other fiber-optic telecommunications components.

While most of this report deals with components that help light signals travel thousands of miles from source to destination, optical solutions can also benefit communications over almost-infinitesimally small distances as well. In particular, these technologies can speed the dataflow between separate components within computers and processing devices. Although still in the design phase, optical integrated circuits and interconnects are predicted to be immeasurably faster than their electronic counterparts. Free-space optical integrated circuits, in which lasers in one component beam signals to detectors in others, are one of the most promising approaches in opto-electronic integrated circuits. George Mason University in Fairfax, Virginia, is developing a terabit-level optical backplane for multiprocessors, called FAST-Net, which uses a novel two-bounce architecture to achieve an optimal combination of high connectivity and low latency.

The polarization controller offered by Corning Applied Technologies can address dispersion problems with next generation fiber-optic equipment.

CORNING GETS A HANDLE ON POLARIZATION

A new line of compact polarization controllers developed by Corning Applied Technologies (Woburn, MA) will help enable greater telecom bandwidths by keeping tightly packed signals cleanly separated. Marketed under the trade name of Acrobat™ series of polarization controllers, these devices can be used to alleviate polarization mode dispersion (PMD)—a growing problem for telecommunications companies upgrading to 10- and 40-gigabit fiberoptic equipment. These devices could also be used in polarization generators, polarization scramblers, polarization multiplexers, and as a value-add to such other optical components as attenuators.

Technology Description

The Acrobat line is based on a class of proprietary materials having high electro-optic coefficients, called OptoCeramic™ technology, which have been developed in part through BMDO SBIR research. Corning Applied Technologies, then an independent company called NZ Applied Technologies, Inc., created an advanced chemical vapor deposition technique that allows a well-controlled growth of materials at very low temperatures. This process can make crystalline structures whose indices of refraction can be changed via electric signals. These materials can perform many of the light routing functions of larger, mechanically driven optical components. Since space is at a premium in fiber-optics environments, OptoCeramic electro-optic materials will enable new device geometries or smaller, more streamlined optical products.

Technology Development and Transfer

In 1999, Corning Applied Technologies introduced the Eclipse™ series of variable optical attenuators based on OptoCeramic technology. These attenuators, only one-tenth the size of other compact attenuators, have since enjoyed widespread industry use, particularly in Europe and Japan.

More recently, the company has released its Acrobat series of polarization controllers, also based on OptoCeramics. These devices convert any input state of polarization (SoP) to any arbitrary output SoP by applying voltage to three independently controlled retardation plates. If incorporated into a polarization mode dispersion compensator (PMDC), Corning Applied Technologies' controllers can be particularly useful tools in combating PMD, which occurs as different polarization modes of a signal travel down a fiber at different speeds, smearing the signal. A PMDC can correct for this dispersion by converting a signal with several polarization modes into a single mode signal. And because Corning Applied Technologies' controllers are solid state, they are radically smaller in size than their mechanical counterparts and can be easily configured into arrays.

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TERACOMM'S TERABIT TRANSCEIVER

TeraComm Research, Inc. (Essex Junction, VT), is developing a fiber-optic transceiver that will offer over a 25-fold increase in the speed at which optical pulses can be generated from a laser beam. By using a high-temperature superconductor (HTS) material to modulate light, this transmitter would operate at over 1,000 gigabits per second (Gb/s), easily beating the 40 Gb/s encoding rates of today's fastest external modulators.

Technology Description

TeraComm's transceiver is based on the superconducting properties of yttrium barium copper oxide (YBCO). YBCO has zero electrical resistance at low temperatures (< 92 K), and possesses very high optical reflectance in its superconducting state. From the application of electric current through a modulator circuit, it can switch between a partially transparent non-superconducting state and a substantially non-transparent superconducting state at picosecond rates (the low temperatures are provided by commercially available cryocoolers). Therefore, a beam directed at this material can be modulated to carry over one terabit of data per second.

To complete the system, TeraComm is developing a patented frequency conversion system that makes the switch compatible with existing near- and mid-infrared (IR) communications systems. In these regions of the spectrum, the photon energy of the light is high enough to break the binding energy of the Cooper electron pairs responsible for superconductivity. Therefore, pulse modulation is done in the far-IR range (around 100 microns), where the photon energy is lower, and the results are converted to wavelengths between approximately 1.3 and 1.55 microns.

TeraComm Research's superconductor-based modulator enables terabit capable transmitters.

The resulting package will be able to send over one terabit per second on a single wavelength. Compared to the next generation of traditional transceivers currently in field trials, which will send about 40 gigabits of data per second on a single wavelength, the TeraComm system will offer 25-times more throughput per wavelength.

Technology Development and Transfer

Development of TeraComm's transceiver was supported in part by BMDO SBIR contracts. The company received research assistance from the University of Vermont and the University of Florida. TeraComm is the first company to successfully demonstrate control of optical transmission in HTS films using electric current. The company has three patents issued covering the use of superconducting devices for optical modulation. TeraComm has another nine patents pending.

In 2000, a venture capitalist provided $1 million in development funds. A prototype is under development, after which the company will market itself to major telecommunications companies. TeraComm expects the transceiver to be sold in a standard 19-inch or 23-inch rack-mountable chassis, with inputs for 16 to 64 synchronous optical network (SONET) OC-192 tributaries and a dual optical output.

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Electrostatic self-assembly is NanoSonic's key to nonlinear optical films.

NANOSONIC'S NANOPARTICLE-BASED NONLINEAR OPTICAL FILMS

NanoSonic, Inc. (Blacksburg, VA), is refining a molecular self-assembly process, called electrostatic self-assembly (ESA), that can be used to produce nonlinear optical (NLO) thin-film materials with nanoscale-level molecular uniformity. The macroscopic engineering properties in these thin films are superior to those found in conventional bulk materials and allow for precise control of their physical properties. The films can be incorporated into beamsplitters, photonic switches, and other photonic components, making these components lighter and faster than their mechanical counterparts.

Technology Description

In ESA synthesis, a substrate is dipped into alternate aqueous solutions containing anionic and cationic materials such as polymer complexes, metal and oxide nanoclusters, cage structured molecules such as fullerenes, and proteins and other biomolecules. Nearly perfect molecular order is achieved by individual molecules seeking least energy configurations (the tendency of any substance to change to the state of least energy). Adsorbed from water solutions, these molecules bond with others already attached at the substrate surface. Material properties can then be precisely controlled through the successive stacking of ultrauniform, nanometer thick layers of the film.

ESA could be used for the commercial manufacture of NLO films, which can be used for many different types of photonic components. NanoSonic found that the ESA processing method yields non-centrosymmetric molecular structures that possess a remarkably large second order NLO response. Moreover the process does not require the electric field polling that other methods require. This second order response allows nonlinear optical devices to alter the frequency, signal strength, or other characteristics of light through an electrical control signal.

Technology Development and Transfer

NanoSonic exclusively licensed nine ESA-related patents from Virginia Tech, which developed the technique. With subsequent BMDO Small Business Technology Transfer Program (STTR) and SBIR contracts, NanoSonic demonstrated the feasibility of using ESA to produce materials with superior photonic properties. ESA has also received SBIR development funding from DARPA, the U.S. Air Force, NASA, the National Science Foundation, and the National Institute of Standards and Technology.

Sometime between 2003 and 2007, NanoSonic will start selling selected thin films and eventually will sell a full line of films and processing machines, while also licensing its processes to other companies. The company's Web site currently lists available products.

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KIGRE'S NEXT-GENERATION WAVEGUIDE GLASS

Kigre's erbium amplifier glass provides up to 100-times more gain than conventional materials.

A recently introduced erbium amplifier glass offered by Kigre, Inc. (Hilton Head, SC), provides 50- to 100-times more gain per unit length than conventional materials used in today's optical amplifiers. This patented material can be used to make miniature, monolithic, high-performance 1.55 µm ion-exchanged lossless splitters, waveguides, fibers, amplifiers, and wavelength-division multiplexing integrated optical devices. Also, with the addition of a multiplexer, filters, and a pump laser, this material—thanks to its superior gain and mechanical flexibility—can become a miniature platform for the next generation of small, high-density optical circuits and integrated opto-electronic devices.

Technology Description

The glass is processed through ion exchange, in which the glass trades ions with a solution to alter its index of refraction. The glass surface is covered by a mask with a narrow (~ 2-5 µm) photolithography pattern used to locally control the ion exchange. The waveguides are initially formed just beneath the glass surface by immersing the glass, at an elevated temperature, in a molten salt bath. The surface waveguides are then buried below the glass surface using a second electric field-assisted ion exchange process. In contrast, competing amplifiers are made from fused silica or fluoride materials that do not exchange ions as readily nor achieve the same gain per unit length and must therefore be larger.

This new phosphate glass has demonstrated an internal gain of up to 3.0 dB/cm in waveguide configurations. The length of material needed for significant amplification is only 2 to 6 cm, far less than the 30 to 60 ft needed for traditional fiber amplifiers. Despite its diminutive size, the material can still split a signal into ten or more separate fibers while keeping each of the outgoing signals as strong as the original.

Technology Development and Transfer

Working with the University of Arizona and Harris Corporation under a BMDO STTR contract, Kigre, Inc., developed this material to meet the military's increased need for smaller, ruggedized, high-performance optical amplifiers and power splitters. Kigre introduced the MM-2 oscillator/amplifier material in 2000 and is now marketing this high-performance athermal phosphate glass laser material to telecommunications component manufacturers. Several major photonic component builders are incorporating this material in their waveguides.

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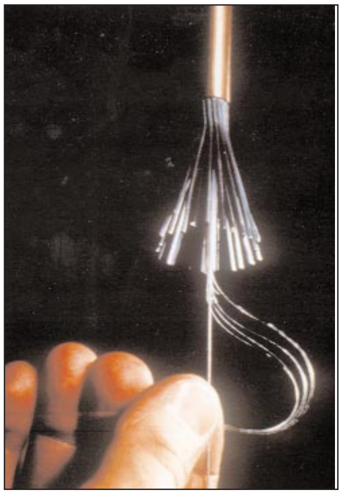
NEW SPAN'S DYNAMIC ALIGNMENT TOOL



Packaging optical interconnects has just gotten a whole lot easier, thanks to New Span Opto-Technology.

New Span Opto-Technology, Inc. (NSOT; Miami, FL), has developed a laser writing method to package optical interconnects. This technology uses dynamic optical alignment to package chips with waveguide components without physically moving them. This interconnect technology, when implemented in a packaging machine, could lower costs of optical interconnects for the electro-optic computing and fiber-optic telecommunications industries.

Technology Description

NSOT's laser writing technology dynamically aligns waveguides to opto-electronic components. The waveguides are made from a proprietary substrate that allows their refractive index to be controlled by a laser writing technique, so components can be assembled together first and then coupled. This dynamic optical alignment eliminates the need to physically move the packaged chips and/or waveguide components. The waveguide substrate also allows for erasure and rewriting, facilitating interconnect line reconfiguration.

This interconnect technology, when implemented in an opto-electronic packaging machine, can be the optical equivalent of a wire bonder for electronic component packaging. The costs of optical interconnects could be lowered through NSOT's streamlined production process, which would dramatically improve yields and speed production times over current techniques. Typically, it is difficult to attach polymer waveguide optical interconnects and other waveguide interconnect lines to opto-electronic transmitters and receivers since great precision is needed for optical alignment. Also, alignments can not be tested before the package is finalized because current production processes do not easily allow for activating and monitoring the components for testing. Using current processes, optical alignment errors can not be easily corrected after the packaging is completed.

Technology Development and Transfer

With BMDO SBIR funding, New Span undertook development of a laser direct-write opto-electronic packaging machine for dynamic optical alignment of laser transmitter arrays, waveguide interconnect lines, and photodetector receiver arrays. BMDO was interested in facilitating a method of producing low-cost optical interconnects for opto-electronic packaged computing systems.

NSOT is developing an opto-electronic packaging prototype in partnership with the Canadian photonic component developer, QPS Technology, Inc. A model should be finished by the end of 2001. The company plans to initially market and/or license the technology to computer and chip manufacturers as well as to interconnect producers.

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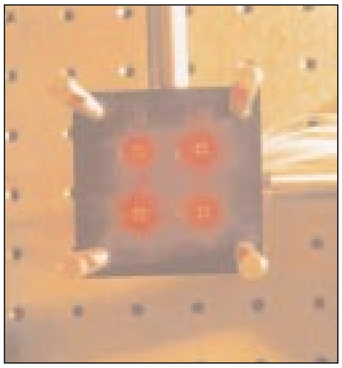

The optical backplane now being developed by George Mason University may revolutionize multichip modules.

OPTICAL BACKPLANE SPEEDS DATA TRANSFER

George Mason University (GMU; Fairfax, VA) is developing an optical backplane for multiprocessors, called Free-space Accelerator for Switching Terabit Networks (FAST-Net), that will provide terabit-level throughput for multichip modules. This technology uses arrays of vertical cavity surface-emitting lasers (VCSELs) and detectors to connect multiple chips together in a global point-to-point fashion.

Technology Description

The FAST-Net concept employs smart pixels that use arrays of VCSELs and detectors to connect multiple chips. In GMU's "two-bounce architecture," arbitrary point-to-point interconnection can be constructed with a maximum of two passes from VCSELs to detectors. This is achieved through the combination of global optical interconnections with local electronic on-chip routing. As a result, the architecture possesses an optimal combination of high connectivity and fast transmission speed that offers a competitive advantage over other designs now being developed.

Thus far, the GMU-led team has demonstrated a backplane consisting of a 4 × 4 array of smart pixels, each containing an 8 × 8 array of VCSEL/detector pairs and plans to replace the arrays with 32 × 32 elements by 2002. With a cluster of 16 chips of this magnitude, terabit-level throughput may be achieved. As part of this technology, the GMU research group created the first working smart pixel array in which high-density silicon switching electronics are integrated into arrays of high-speed gallium arsenide opto-electronic detectors. The FAST-Net concept also employs a CMOS chip that contains the drivers, receivers, and digital logic associated with the routing of electronic I/O and computational elements.

Technology Development and Transfer

FAST-Net was initially funded by the Air Force Office of Scientific Research (on behalf of the Science and Engineering Research Training program) and DARPA. As part of an effort to facilitate optical interconnects in computers, the BMDO IST program contributed $100,000 to develop the beam steering science to make possible far denser clusters of VCSELs and detectors.

In order to pursue commercial opportunities for VCSEL-array based technology, primary investigator Dr. Michael Haney and other researchers have formed a company called Applied Photonics, Inc. (AP; Fairfax, VA). AP is investigating commercial paths for the technology and its associated offshoots, including accelerators for image and signal processing, general purpose switching fabrics for multiprocessor communications, and high-performance forward error correction communications decoding.

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INDEX OF SUBJECTS

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